2004 DOE Hydrogen, Fuel Cells, & Infrastructure Technologies

Development of High-Temperature Membranes and Improved Cathode Catalysts

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UTC Fuel Cells

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This presentation does not contain any proprietary or confidential information.

Objectives

- **Ultimate goals**:
  - Develop and demonstrate an advanced polymer membrane able to operate at near-ambient pressure (1-1.5 bar) in the temperature range of 120 to 150ºC, capable of meeting DOE goals for performance
  - Develop and demonstrate improved Pt-based cathode catalysts that will enable the reduction of Pt loading to 0.05 mg/cm^2 and meet DOE goals for performance.

Objectives (high-temp membrane)

- Optimize candidate membranes for operation at 120ºC, 50% RH
- Characterize membranes for suitability in high-temperature fuel cell
  - *ex-situ* testing
    - » conductivity at various humidity
    - » water uptake
    - » tensile strength
  - in-cell tests:
    - » performance at 120^{o}C and 50% RH, 1.5 kPa
    - » 100 hours stability tests
    - » fuel crossover
    - » elemental analysis of the exhaust water

Objectives (improved cathode catalyst)

- Select most promising alloy catalysts for evaluation in fuel cell
- Optimize fabrication processes
- Conduct testing to evaluate ***performance and stability*** (in liquid cell).
- Compare performance of submitted catalysts to that of TEC10E50E (TKK's 46.7% Pt/C)

Budget

- Total funding for the project is $9.5 M
- UTC FC cost shares 20% on this project, including cost share by IONOMEM corporation and UTRC.
- UTCFC spend in FY03 is $722k; DOE spend is $2.9 M, for a total project spend of $3.32 M

Technical Barriers and Targets

- DOE Technical Barriers for Fuel Cell Components
  - P. Durability
  - Q. Electrode Performance
  - R. Thermal and Water Management

- DOE Technical Target for Fuel Cell Stack System for 2010

– Durability	5000h
– CO tolerance (2% air bleed)	500ppm ss /1000 ppm transient
– Power density*	650 W/L excluding H2 storage
– Electrode performance	0.2 g Pt/kW

* operate in thermal and water balance

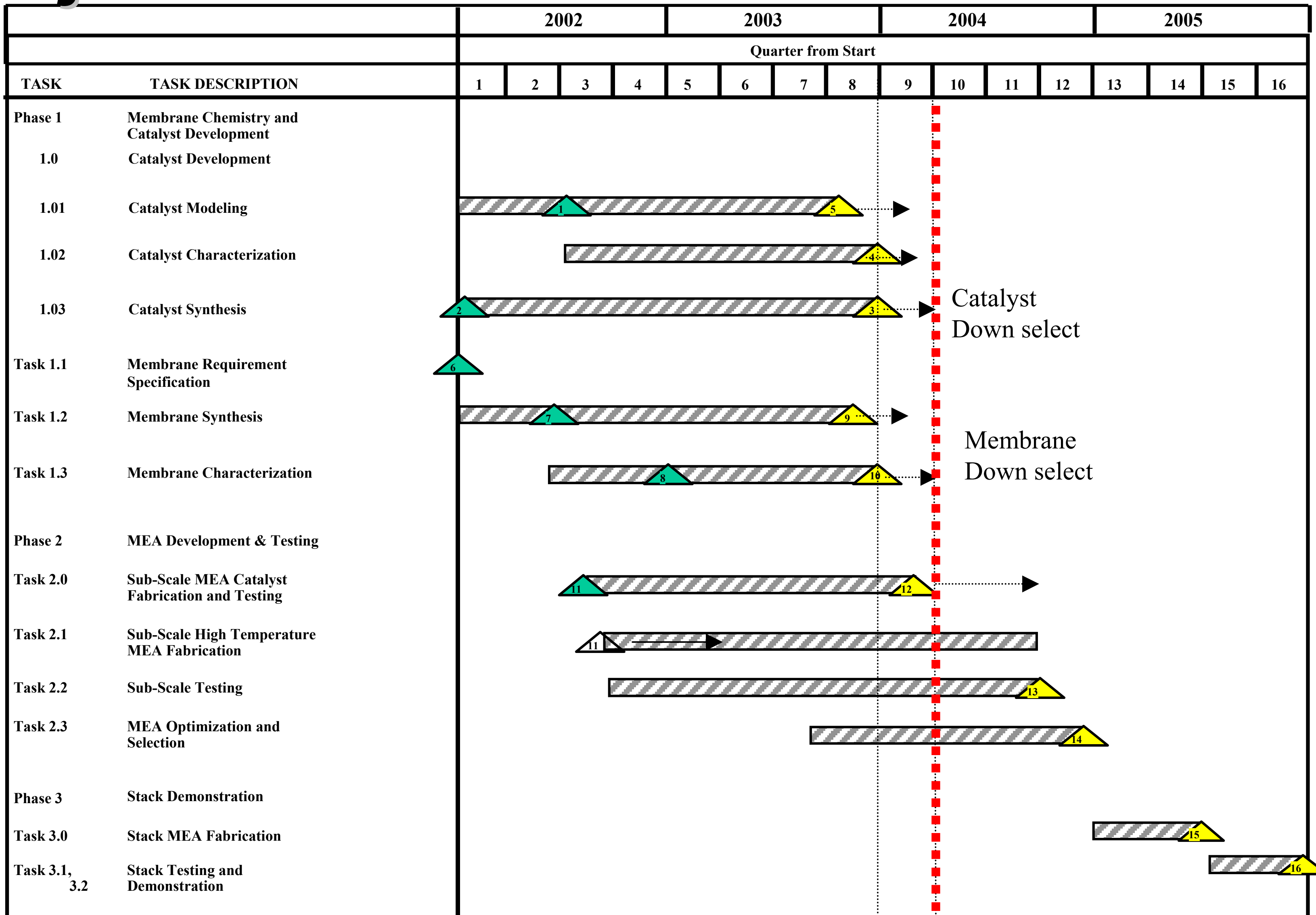
Approach

- **Phase 1**: Synthesize, characterize high-temperature membranes and improved Pt-based catalysts. Compare to issued specifications
- **Phase 2**: Fabricate, optimize, and test laboratory-scale catalyst coated membranes with top two candidates from phase 1.
- **Phase 3**: Fabricate full-size CCM's using best membrane and best catalyst, test in multi-cell stacks.

Project Safety

- All testing is done in well-ventilated, automated test stands with hydrogen detection and safe shutdown procedures
- All test hardware for program has been tested and evaluated in contractor safety review process

Project Timeline



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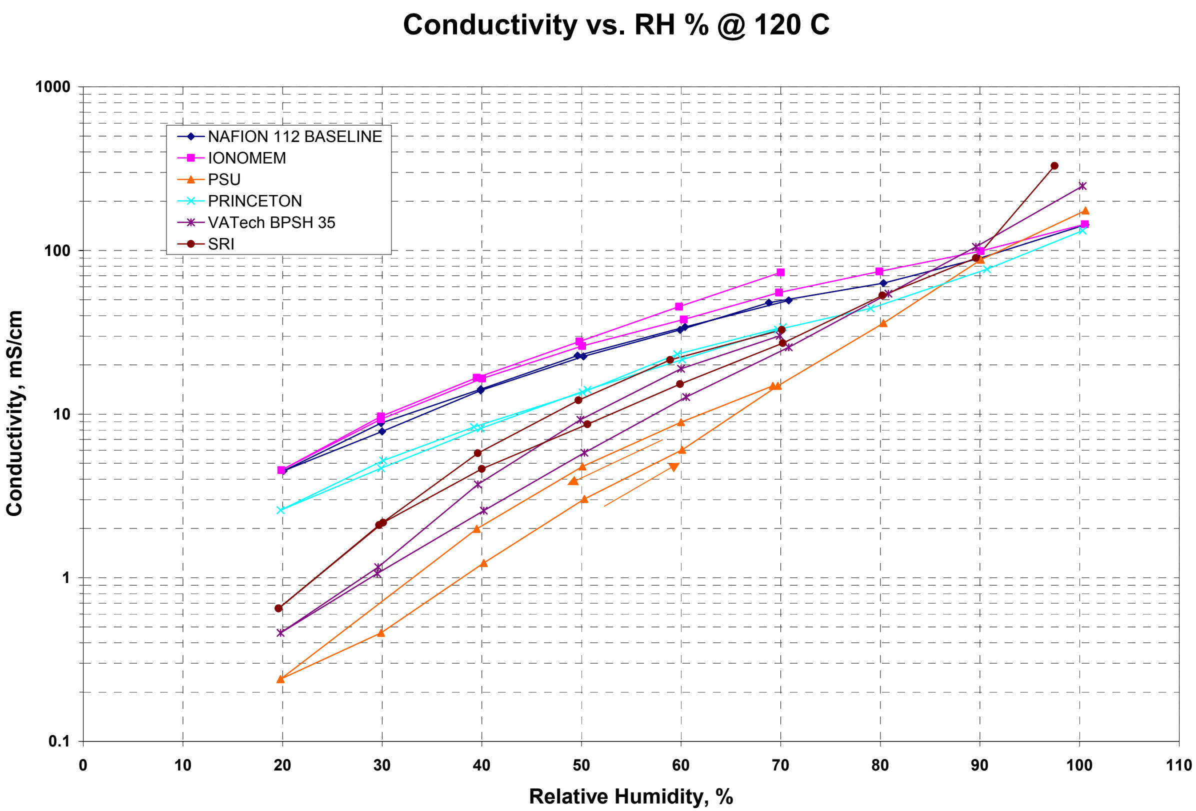
Conductivity vs. DoE Targets BekkTech results



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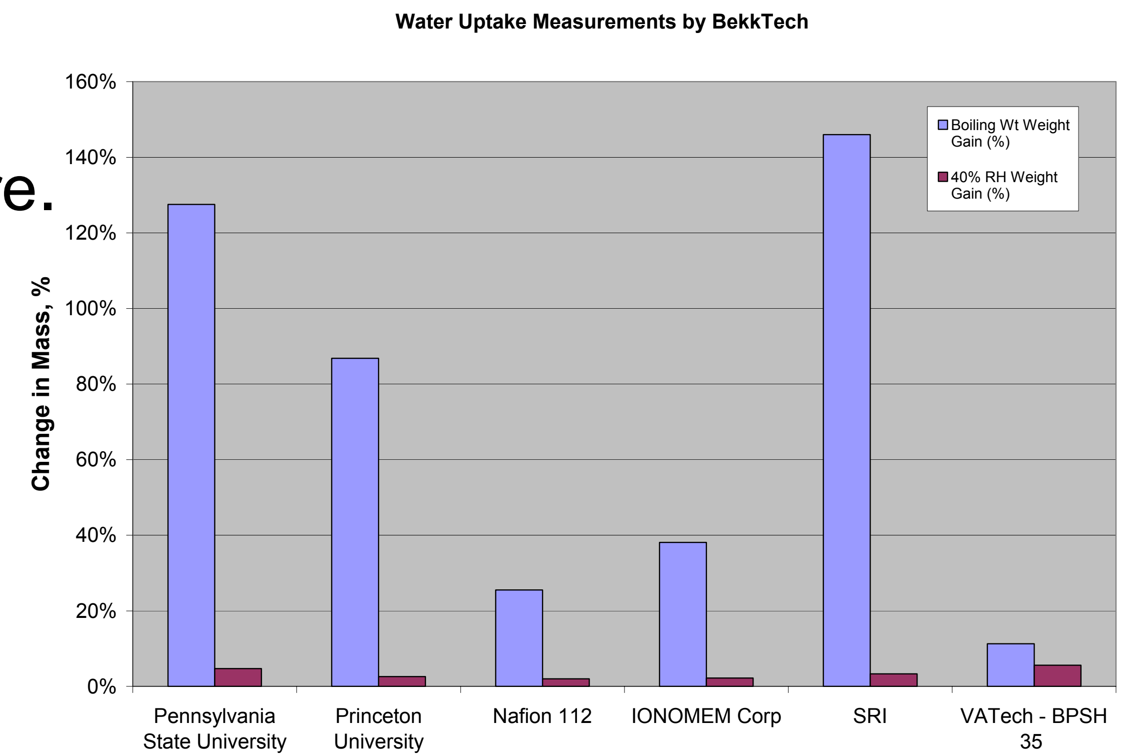
Water Uptake

- Vapor conditions
  – membranes equilibrated at 40 % RH vapor at 120 ^{o}C.
- Liquid boiling
  – Ambient pressure.



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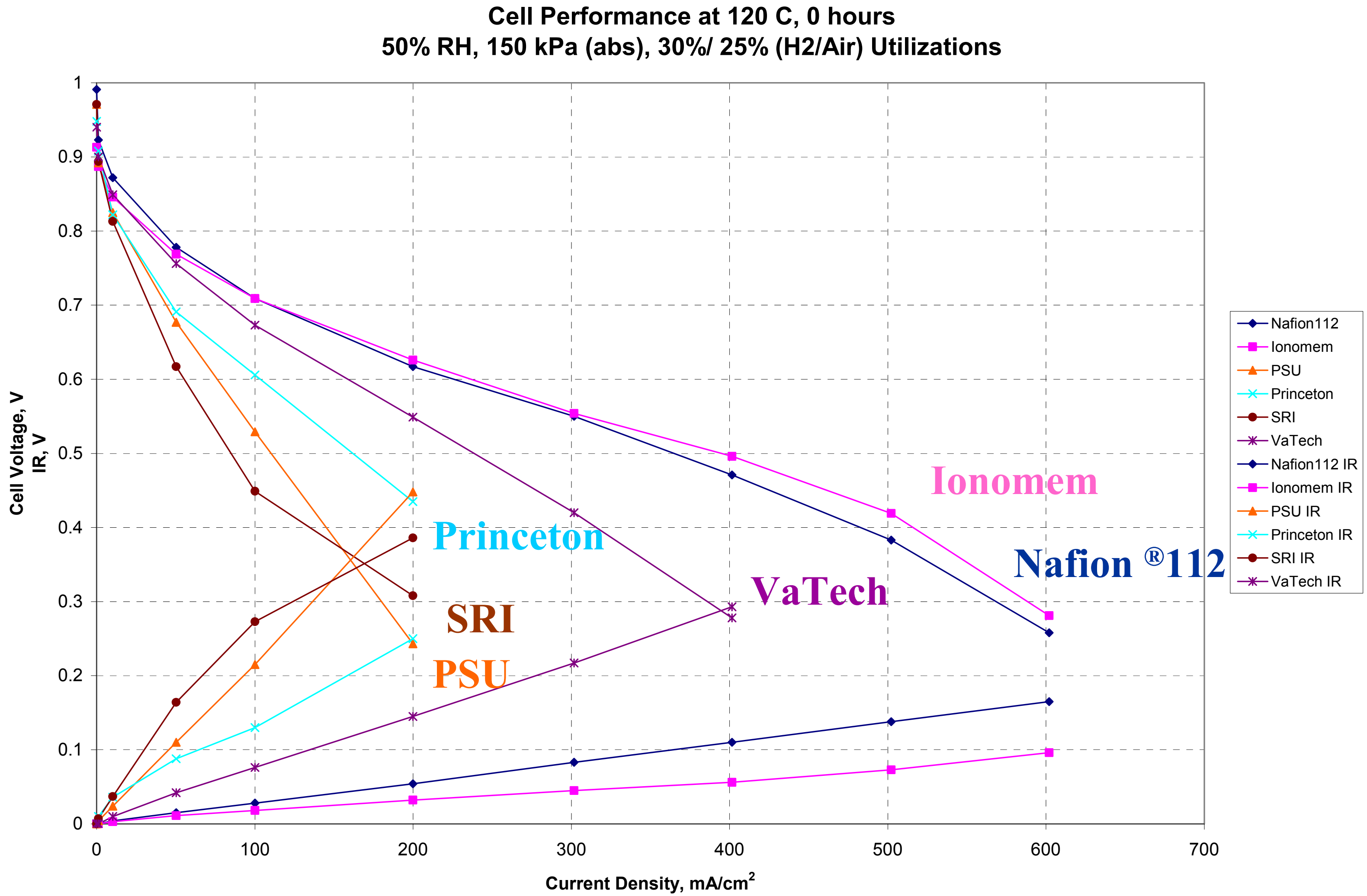
FC Initial Performance: H_2/Air



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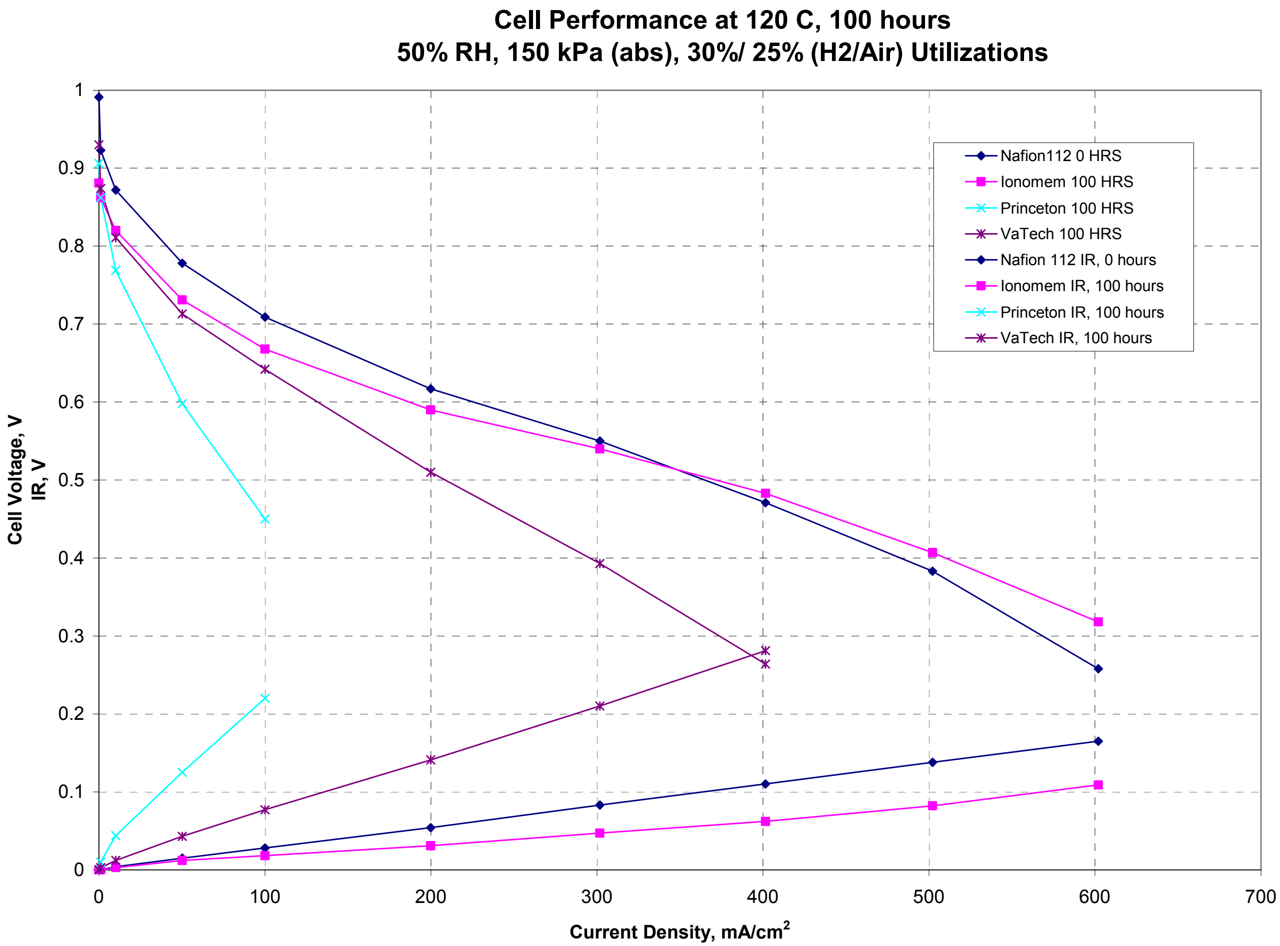
FC 100 Hour Performance: H_2/Air



- SRI, PSU membranes failed before 100 hours

Downselect Scoring

- Nafion is the standard

Criteria	Criteria Subcategory	Weight	Ranking (1 to 5, 5 = highest, 0 = failure)					
			Nafion	Ionomem	VaTech	Princeton	SRI	PSU
Conductivity – 50 % Total	20% RH*	0.125	3	4	1	2	1	1
	50% RH*	0.25	3	4	2	2	2	1
	100% RH*	0.125	3	3	4	3	4	3
Water Uptake - 20% Total	40 % RH Vapor	0.15	3	3	1	2	2	2
	Liquid	0.05	3	2	5	1	1	1
Performance – 30 % Total	IR BOL	0.1	3	4	3	2	1	2
	IR EOL	0.1	3	4	3	1	0	0
	crossover EOL	0.1	3	1	3	3	0	0
SCORE = Σ(Weight * Ranking)			**3.0**	**3.325**	**2.425**	**2.075**	**1.575**	**1.3**

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Downselect Results

- Ionomem next phase (CCM opt, scaling)
- **Nafion 112** ——————————
- VaTech improvement of the properties
- Princeton failed
- SRI failed
- PSU failed

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Electrochemical Area and ORR Activities (liquid cell)

Catalyst	ECA, m^2/g (button)	ORR activity, 0.9V vs. RHE	
		$\mu A/cm^2$	mass activity, A/g Pt
TKK- Pt/C	**107**	**90**	**96**
UTC-PtCo/C	74	274	203
UTC-PtIrCo/C	110.6	166	184
USC PtCo/C	29.6	231	68
NEU-PtCo	40.2	300	120

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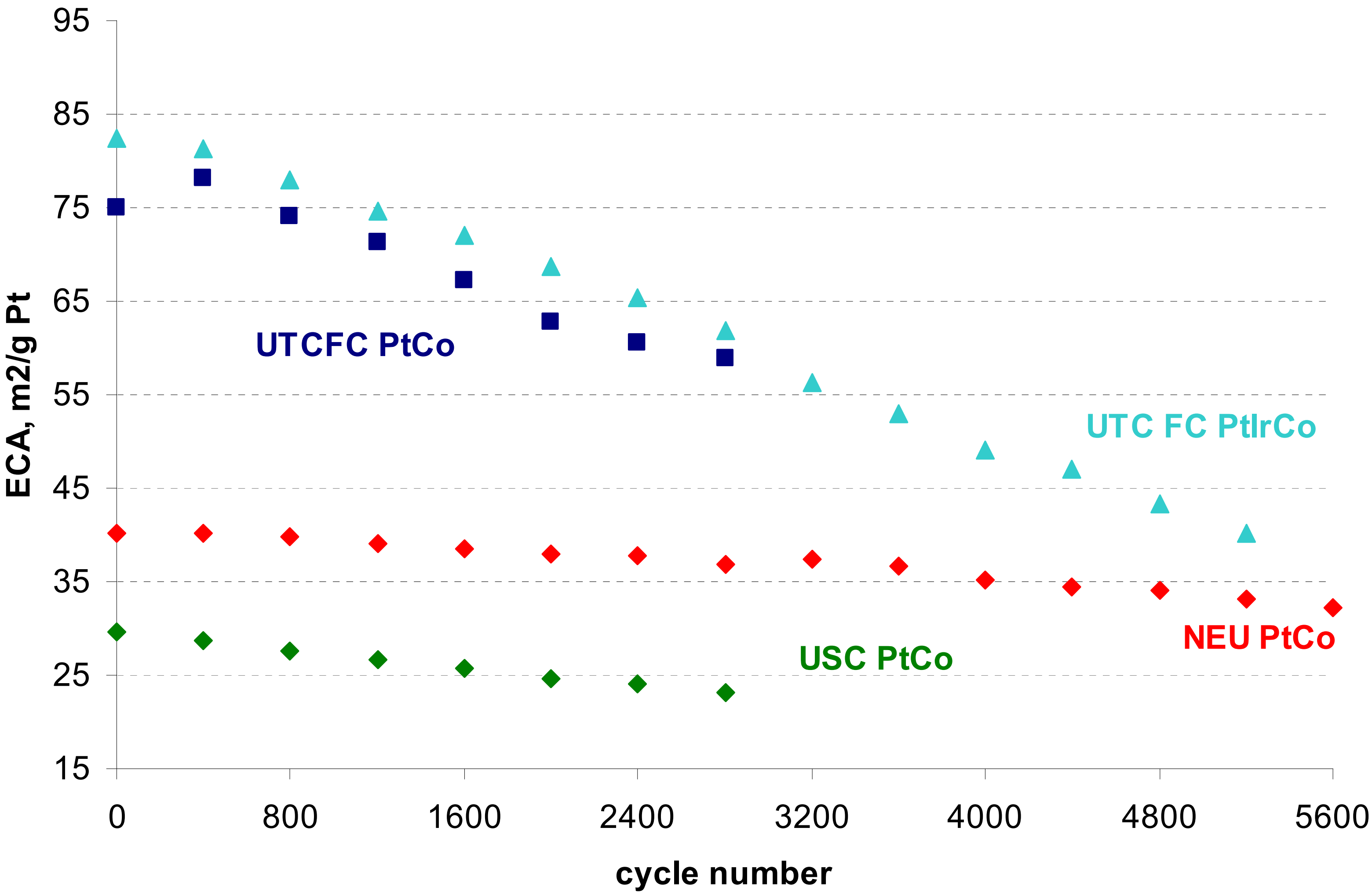
Cyclic Durability Test



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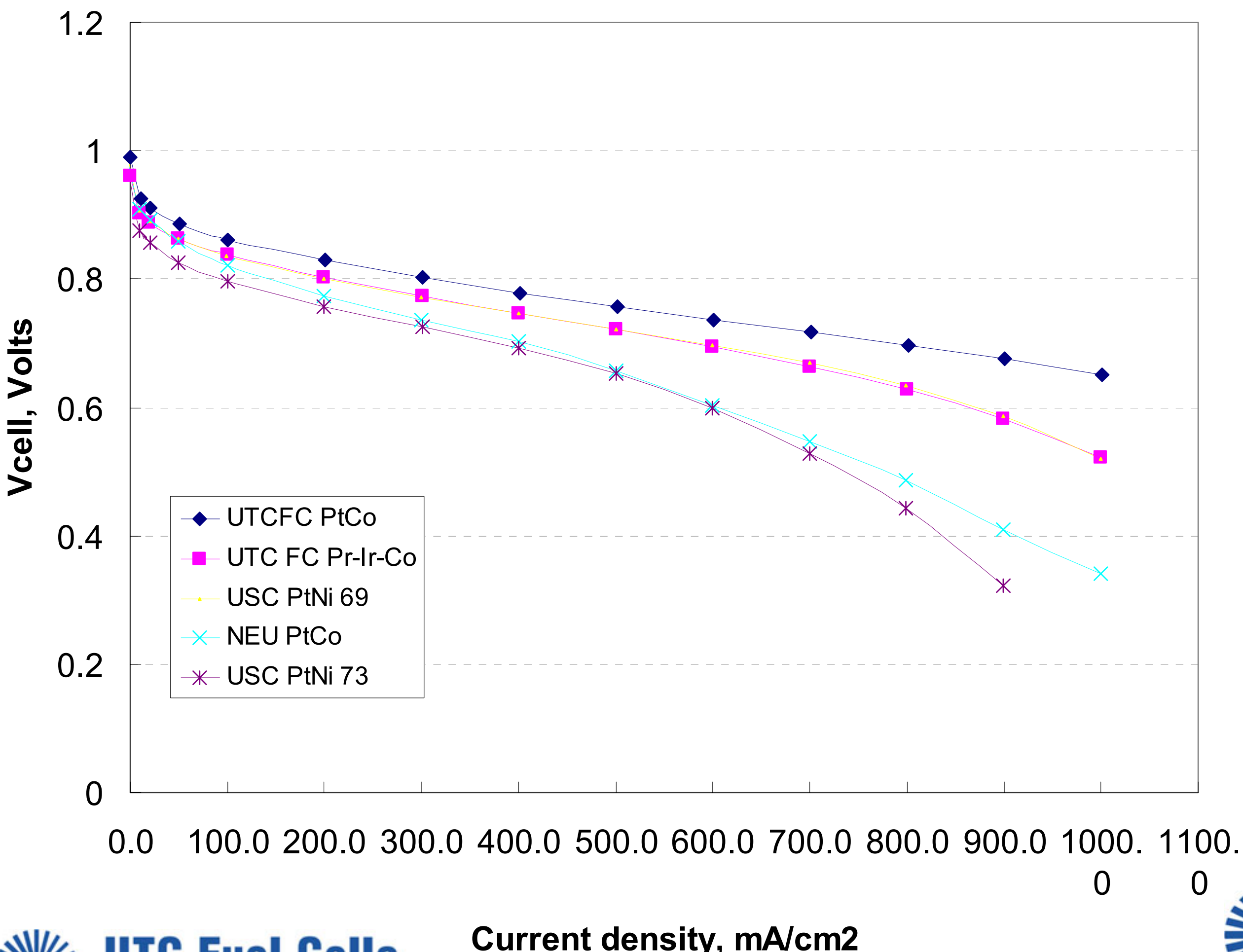
Subscale Fuel Cell Performance of the Catalysts



Anode: TEC10E50E Pt/C,

Membrane: Nafion112,

Temperature: 65^{o}C,

Pressure: 101kPa,

Fuel: H_2,

Oxidant: air

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Downselect Results

UTC FC PtCo / C

UTC FC PtIrCo / C

next phase: CCM optimization and scale-up

TKK Pt /C TEC10E50E

NEU PtCo / C — improvement of the properties

USC PtNi — stability failed

USC PtCo / C — performance failed

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Interactions and Collaborations

Group	Principal Investigator	Approach
IONOMEM	Mr. Leonard Bonville	Hygroscopic solid ion conductor (e.g., zirconium phosphate,etc) filled Nafion®)
Penn State University	Prof. Digby Macdonald	Sulfones and sulfoxides of aromatic PPBP and aliphatic PVA. Covalent sulfonic acid bonded PEEK, PBI and PPBP
Princeton University	Prof. Andrew Bocarsly	Layered sulfonated Polystyrene/Fluoropolymer system
Stanford Research Institute	Dr. Susanna Ventura	Sulfonated PEEK-PBI-PAN
Virginia Tech	Prof. James McGrath	Sulfonated Poly(arylene ether sulfone)

UTRC
Dr. Ned Cipollini
MEA fabrication and optimization

UTC FC
Dr. Jeremy Meyers, Dr. Lesia Protsailo
General coordination. System optimization. Stack demonstration

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Interactions and collaborations

Group	Principal Investigator	Approach
Northeastern University	Prof. Sanjeev Mukerjee	Micellar Pt nano cluster synthesis, colloidal sol synthesis of binary Pt alloys.
University of South Carolina	Prof. Branko Popov	Pulse electro-deposition of Pt and Pt alloys on Carbon. [Pt and Pt-X, X=Fe, Ni, Co, Mn and Cu]
UTC Fuel Cells	Dr. Jeremy Meyers, Dr. Lesia Protsailo	Carbothermal synthesis of binary and ternary Pt alloys. [Pt-Ir-X and Pt-Rh-X, [X =Ni, Co and V]]
Case Western Reserve University	Prof. Al Anderson	Quantum chemical modeling of Pt alloys and ORR.
UT Research Center	Dr. Ned Cipollini	Reproducible and stack size CCM fabrication.

* Consulting on characterization techniques
Phil Ross, LBNL

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Future work

- Optimize MEA with Nafion/hygroscopic compound composites for high-temperature operation, demonstrate performance in cell
- Improve properties and low-RH conductivity of BPSH by composites and investigation of ionic liquids
- Optimize MEA for PtCo, PtIrCo performance on H2/air, demonstrate performance in cell
- Optimize particle size for PtCo formation by colloidal synthesis
- Construct and test multi-cell stack of best membrane system and best catalyst system.